



When the
Universe
Took a **U-Turn**

B G Sidharth

 World Scientific

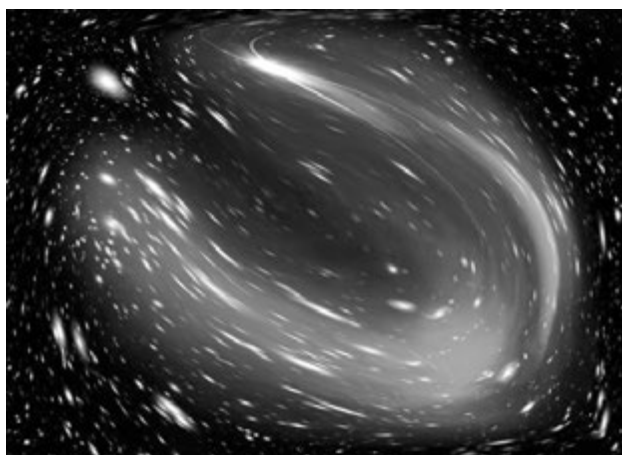
 **Documents**
Document Sharing Hub

When the
Universe
Took a **U**-Turn

This page intentionally left blank

Copyright World Scientific Publishing Co.

When the Universe Took a U-Turn



B G Sidharth

B M Birla Science Centre, Hyderabad, India

 **World Scientific**

 **Documents**
Document Sharing Hub

Copyright World Scientific Publishing Co.

Provided by IHS Markit under license from WILEY. SINGAPORE • BEIJING • CHENNAI • HONG KONG • TAIPEI • CHENNAI
No reproduction or networking permitted without license from IHS

Not for Resale,

Full document details: WSPC WHN UNI TK A U-TRN 2009

Published by

World Scientific Publishing Co. Pte. Ltd.

5 Toh Tuck Link, Singapore 596224

USA office: 27 Warren Street, Suite 401-402, Hackensack, NJ 07601

UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library.

WHEN THE UNIVERSE TOOK A U-TURN

Copyright © 2010 by World Scientific Publishing Co. Pte. Ltd.

All rights reserved. This book, or parts thereof, may not be reproduced in any form or by any means, electronic or mechanical, including photocopying, recording or any information storage and retrieval system now known or to be invented, without written permission from the Publisher.

For photocopying of material in this volume, please pay a copying fee through the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, USA. In this case permission to photocopy is not required from the publisher.

ISBN-13 978-981-4277-81-5

ISBN-10 981-4277-81-9

Printed in Singapore.

Dedicated to the memory
of my father and mother



Copyright World Scientific Publishing Co.

Preface

In the late sixteenth century, the German scholar Johannes Kepler inherited a huge amount of data about the positions of the planets, from his mentor Tycho Brahe who had just passed away. The motivated Kepler set upon improving the Greek model of the universe, armed with the latest figures. His technique was all too familiar as it had been tested for nearly two thousand years. He would have to add one more sphere or epicycle as it was called, to the orbit of a planet. Or he would have to slightly shift the centre of a circular orbit. Things like that. But try as he might, and that meant several years of frantic calculations, he could not bridge a tiny discrepancy between Brahe's observations and the model of the universe. The difference arose for the planet Mars, and it was miniscule, one might even say, not worth all these trials and tribulations. Kepler himself confidently declared that this minute discrepancy was really pointing the way to a reformation of astronomy. And so it did! The two thousand years old Greek model of the universe collapsed, when Kepler discovered that by using a slightly non circular orbit, an elliptical orbit in fact, the discrepancy vanished. This heralded the beginning of modern science.

Early in the last century, a similar situation prevailed. Breath taking progress had been made in science in the preceding centuries that had witnessed unparalleled contributions from the likes of Isaac Newton, James Clerk Maxwell and others. And yet there was a small something that didn't add up, a fly in the ointment. This was in the form of the results of some recent experiments which could be explained by the beautiful theories of physics and the universe, almost – but not quite. Once again science took a tumble. The new and minute discrepancies gave birth to the special theory of relativity, the general theory of relativity and Quantum theory, which undoubtedly were the intellectual peaks of the last century. They have gone

a long way in shaping and reshaping our concepts of the universe and indeed technology which touches our lives. At last after millennia of scientific and intellectual quest, everything seemed to be falling in to place.

However, as the last century drew to a close certain discrepancies surfaced. Some of them were miniscule by any standards. For instance the mysterious particle called the neutrino was supposed to be massless. It turned out to have the slightest of masses, much, much lighter than the lightest known particle, the electron.

The realization has been creeping into the scientific community, that we are missing out on something. The awe inspiring, mind blowing contributions of the last century may not be the last word. These concepts were bizarre and upturned the cosy picture of the universe which was inherited from the time of Newton. But perhaps the radical ideas left behind by twentieth century physics are no more than a fore taste. A new cosmos seems to be emerging which is even more bizarre, even more crazy than we could ever imagine. We may well be at another dramatic turning point in our intellectual evolution and conception of the universe, confronting unexpected, even unimaginable concepts of spacetime and the universe. The story is still unfolding.

I have tried to capture the mood and spirit of this new paradigm shift in the following pages. Undoubtedly, in the course of simplification, to reach out to a larger audience, precision would be lost. This is because it is not possible to go into the merciless technical detail. In the process, to help the cause, I have here and there repeated certain ideas and concepts, and have almost always tried to keep the references at a popular level. I am grateful to Prof. Walter Greiner of the Frankfurt Institute of Advanced Studies for useful advice and also my secretary Mrs. Y. Padma and my wife Dr. B.S. Lakshmi for invaluable help in the preparation of the manuscript. My thanks are also due to Prof. K.K. Phua and Lakshmi Narayan of World Scientific, for unstinted cooperation.

B.G. Sidharth

Contents

<i>Preface</i>	vii
<i>List of Figures</i>	xi
1. The Lord is subtle, but defies commonsense!	1
2. You can be younger than your grandson	11
3. God does not play dice, or does He?	31
3.1 The Classical Catastrophe	31
3.2 Particles Disguised as Waves	37
3.3 The Paradox of Reality	47
4. Time is running backwards isn't it?	57
4.1 Dealing With Billions	57
4.2 Time, the Eternal Enigma	66
5. On a collision course	75
5.1 Bits of Atoms	75
5.2 Fundamental Forces	86
5.3 Quantum Gravity	93
5.4 Strings and Loops	100
5.5 A Critique	109
5.6 Smashing the Atoms	122
6. Law without law	127
6.1 The Perfect Universe	127

6.2	The Lawless Universe	138
7.	When the universe took a U turn	151
7.1	The Exploding Universe	151
7.2	Birth Pangs of the Universe	152
7.3	The Infant Universe	154
7.4	A Dark Mystery	156
7.5	The U turn	158
7.6	A Darker Mystery	160
7.7	Other Footprints	164
7.8	A New Dawn	168
7.9	Blow out Infinity	171
	<i>Bibliography</i>	177
	<i>Index</i>	181

Copyright World Scientific Publishing Co.

List of Figures

1.1	Greek epicycles and effective motion	5
1.2	An elliptic orbit	7
1.3	The stone tends to rush off along the tangent if the string snaps	8
2.1	Foucault's pendulum	12
2.2	Stationary and moving charges	15
2.3	Boy running with and against the ship's motion	16
2.4	Light Clock	21
2.5	Ball falling in a stationary elevator	24
2.6	Ball floating in an accelerated elevator	24
2.7	The deviation and bending of light	26
2.8	The bending of light observed during a total solar eclipse	28
2.9	Different speeds of a falling object at different heights	30
3.1	Rutherford's Gold Foil Experiment	34
3.2	Standing Wave	37
3.3	The addition of waves	38
3.4	Interference of waves	39
3.5	The uncertainty spread of a particle	41
3.6	The Stern-Gerlach Experiment	42
3.7	The double slit experiment	46
3.8	Schrodinger's Cat	49
3.9	EPR paradox experiment	51
4.1	Diffusion of molecules	61
4.2	The universe as an apple	67
4.3	Projectiles and Satellite	69
4.4	A random walk	72

5.1	Neutrino Spin	89
5.2	How smooth is the curve?	100
5.3	Regge resonances	101
5.4	A simple pion model	102
5.5	A scattering process from two different perspectives	103
5.6	Noncommutative geometry	105
5.7	Geometry as beads and wires	108
5.8	A closer look at a “bead”	108
6.1	Some perfect solids	128
6.2	Sponge and fisherman’s net	131
6.3	Random motion of a molecule	134
6.4	Rapid unphysical fluctuations	136
6.5	Travails of a traveling salesman	139
6.6	IQ spread of people	143
7.1	Planck “Springs” in the quantum vacuum	163
7.2	Precession of perihelion of planet Mercury	165
7.3	The universe of universes is but a bubble. Each dot is a universe in itself	173

Copyright World Scientific Publishing Co.

Chapter 1

The Lord is subtle, but defies commonsense!

“The way that can be walked is not the perfect way, the word that can be said is not the perfect word”

-Lao Tse, c. 4th Century B.C.

Malcom, an American astrophysicist was peering into his computer screen carefully examining the tons of data beamed back by NASA’s Gamma Ray Large Array Space Telescope, GLAST. This had been blasted off in mid 2008 to relay information on Gamma Rays being belched out from the deepest recesses of the universe. Was there a clue that could end the reign of Einstein’s Special Theory of Relativity, a theory that had withstood a century of scrutiny?

A continent away, Jacob, a particle physicist in Europe was meticulously computing, using the equally voluminous data being churned out by the recently kick-started Large Hadron Collider (LHC), in CERN, Geneva. Was there a faint footprint of the Higgs particle that had been eluding detection for over four decades? Was the standard model of particle physics erected more than three decades earlier, the last word?

The year, 2010. Both the GLAST and the LHC are multi-billion dollar contraptions, the culmination of years of planning and labor, eagerly awaited for several years by physicists the world over. These would test two of the greatest intellectual theories fashioned out by the human mind in the last century of the millennium, the Theory of Relativity and Quantum Mechanics.

The story begins some 12000 years ago. The Earth was a frozen planet, much of it a freezing white sheet of ice. Human beings lived in caves and caverns, prowling and wandering like polar bears. They wore furs and used crude stone tools in their efforts to hunt down wild animals for food. But

already the last of the great ice ages had begun to thaw and a new lifestyle was beginning to emerge. Agriculture. People now had to settle down in habitats to tend to their crops and domesticated animal herds.

As people looked around at the universe - the earth, sky and nature, in bewilderment, they discovered that oftentimes hostile nature could also be an ally in the struggle for survival. For example, they could use clubs or fire and later the wheel.

The advent of agriculture was a major departure in life style from the hunter gathering ways and days. People soon discovered that the drama in the heavens - the rising and setting of the sun, the phases of the moon and the progression of the seasons provided a clock cum calendar so essential for the new science of cultivation. Roughly, the starry sky was the dial of a clock, while the sun and moon were like the hands that indicate the passage of time.

The heavens threw up the different units of time. For instance the sun rises, sets and rises again. This gives birth to the 'day'. The moon passes through its various phases - from full moon through crescent moon back to full moon. This gives rise to the 'month'. Then, the sun appears to have another motion apart from rising and setting. This is a slow west to east drift through the stars. This means that exactly at sunset each day, we see different groups of stars or constellations as we call them, in the west. But after a year, we return to the same pattern of stars at sunset. These basic units of time were used for framing the earliest calendar, which guided ancient agricultural activity.

However as the precision of observations increased, crude calendars gave way to more precise ones in order to keep a track of the seasons, so essential for sowing, harvesting and other agricultural activities. Briefly, the problem which ancient man faced was the following. The month consisted of twenty nine and a half days, while the year consisted of three hundred and sixty five and one fourth days. So twelve months would be three hundred and fifty four days, some eleven days less than the true year. You might say, so what? But this difference of about eleven days would pile up. After about sixteen years, the difference would be about six months - and winter would be summer and summer in winter. A mess!

The ancient Indian calendar, perhaps the precursor of the Sumerian and later calendars overcame this mismatch by using a simple technique. As every three years of twelve months would lead to a shortfall of some thirty three days, an extra month was added every three years, a leap month.

Of course this scheme had to be tweaked even more to bring into step the month and the year.

The point is that the months are computed using the moon. This is very accurate because we can see the backdrop of stars when the moon is present in the sky. However the year is dictated by the sun – for instance the interval between the time when the length of the day (sunrise to sunset) exactly equals the length of the night to the next such occasion. All this happens at the vernal equinox. Similarly there is the autumnal equinox or the winter solstice signalling the longest night and the shortest day and the summer solstice where the opposite happens. It is the year which is important for agriculture, because it is so intimately connected with the seasons. What we are trying to do is to match the months of moon with the year of the sun. Small differences will have to be eliminated. For instance even if we add one extra month every three years, there is still a residual difference of a few days. Such a calendar is called a luni solar calendar and has been the hallmark of ancient agricultural civilizations.

However, one could just use the month as a unit and try to fit in the three hundred and sixty five and one fourth days of the year. Twelve months. This is essentially what has been done over the past two thousand years. Our modern calendar for instance manages to fit in three hundred and sixty five days within the twelve months. The one fourth day could be adjusted by having three years with three hundred and sixty five days and a fourth year, the leap year with an extra day. Again this broad scheme had to be fine tuned to make it precise.

As thought evolved, people began to try to understand and explain what they saw. In the process they built models, that is described new phenomena in terms of concepts or vocabulary they already knew. This is what every growing child does. The pattern has been going on ever since.

The earliest known model builders were the composers of the Rig Veda, several thousand years ago [1]. With amazing insights, they could guess that the apparently flat earth was actually round, describing the earth and sky as two bowls. They went on to describe the sun as a star of the daytime sky and even asked, how is it that though the sun is not bound it does not fall down? And so on and so on. This is an example of a pattern that has repeated itself over the ages: the breakthroughs have been counterintuitive, that is, have defied the apparent dictates of commonsense.

As we will see over and over again, the universe is not what it appears to be. The answers may go against our intuition which is based on our experience. An example of an intuitive model of the universe would be that

of the ancient Egyptians for whom the sky was a ceiling, supported at the extreme ends by mountains. It is difficult to break out of the intuitive mold. Such a departure is often forced upon us, due to the utter inadequacy of old concepts to describe new phenomena.

Perhaps the earliest model of what we today call microphysics or atomic or subatomic physics was proposed by the ancient Indian thinker Kanada who lived around the seventh century B.C. For him the universe was made up of ultimate sub constituents which were in perpetual vibration. Later, Greeks also had an atomic theory, which they may or may not have acquired from India. But there was a crucial difference. Their atoms were static. These concepts were brilliant, but they were much too counterintuitive, much too fanciful to be accepted wholeheartedly. How could smooth marble, for example, be composed of separate discrete bits? They remained on the fringes of speculation and philosophy for over two thousand years.

The insights of the Vedas were camouflaged in allegory and this oral tradition was lost over the millennia. Our legacy of modern science came from the more intuition and experience based Greeks who were expert geometers. They built up over a few centuries, an even more complex cosmic scheme in which the flat earth was at the center, surrounded by a series of transparent material spheres to which the various heavenly objects like the sun, moon, planets and stars were attached.

Why the material or crystalline spheres? Well, they were necessary, for, otherwise they would have had to explain why the moon doesn't crash down on to the earth, for example. Newton was not the first man to notice that the apple falls down!

These were spheres because Plato the Greek thinker, had preached that the circle (or sphere) was a perfect object, due to its total symmetry. Plato and his followers were obsessed with this notion of symmetry and perfection, with origins in geometry. His school, for example proclaimed that no one was allowed in, who did not know geometry. This legacy has come down over the ages – even Einstein swore by geometry. The moon is round, and so is the sun. In a perfect world therefore, everything had to be circular or spherical. The modern word “orbit” comes from the Greek word, orb, for circle. Furthermore these spheres would have to be rotating – otherwise how could we explain the heavenly drama such as the rising and setting of the stars.

As the observations sharpened, the above simple model, first put forward by Anaximenes around 500 B.C. needed modifications [2]. For instance the center of a sphere would not coincide exactly with the earth, but rather

would be eccentric, that is, slightly away from it. Then the spheres themselves had to carry additional spheres called epicycles, themselves spinning and the objects were placed on top of the epicycles. Later, around 100 (A.D.), Ptolemy the Librarian of the Great Library of Alexandria compiled all this knowledge in two astronomical treatises only one of which, the great *Astronomer* or *Almagest* survived. The Ptolemaic universe was a complicated tangle of such spheres and epicycles and epi-epicycles, undergoing complex circular motions. It was a geometrical wonder though. (Cf.Fig.1.1).

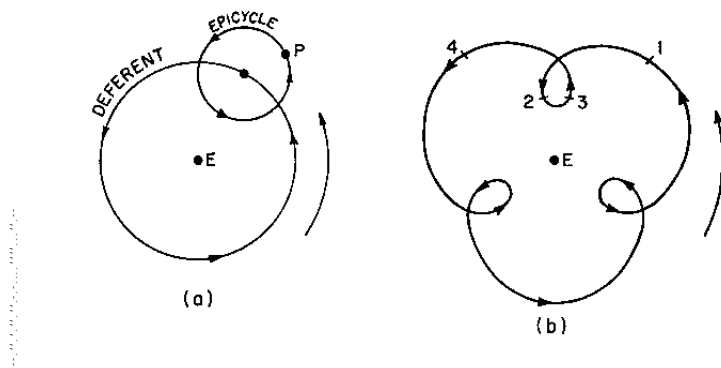


Fig. 1.1 Greek epicycles and effective motion

These basic ideas survived for nearly two thousand years, till the time of Copernicus. Nicolaus Copernicus was born in Torun, today in Poland, to a family dealing with copper. By the time he was forty, he settled down in Frauenberg, Germany. In the sixteenth century, in a commonsense defying leap of faith, he put the sun rather than the earth at the center, though much of the Greek baggage like transparent material spheres and the tangle of epicycles remained. Nevertheless it was a dramatic, even absurd idea. Imagine the solid earth with the trees and buildings hurtling through space! Another contra idea that was smuggled in was that the everywhere flat earth was actually round.

Though such contra ideas had been put forward by a Greek, Aristarchus, more than two thousand years before Copernicus, they were rejected even by the scholars. They argued decisively over the centuries that earth could not be traveling or rotating.

By now there had been a major development. Unfortunately the Greeks did not know of the positional system of notation and so their numbers were the clumsy so called Greek numerals. These were not amenable to algebraic computations. However the positional system of notation including the all important concept of zero were already well established in India over two thousand years earlier. No wonder that the ancient Indians were way ahead in computational techniques. For example Brahmagupta in the seventh century was already using second order differences in his interpolation formulas. So also Aryabhata was using Trigonometrical tables and computations around the same time. Moreover, calculus, an indispensable tool, was being used for planetary calculations at least six centuries before Newton [3].

In the eighth century the founder of Baghdad Khalif Al Mansoor invited Indian scholars, and one in particular, Kanka of Ujjain in Central India acquainted the Arabs with not only the decimal system but also Brahmagupta's computational techniques. The decimal system itself reached Europe through Spain as late as the twelfth/thirteenth century. Two mathematicians, Fibonacci and later Abelard of Bath learnt of this new technique and it soon caught on. Copernicus [4] and later astronomers were armed with this new and powerful tool of mathematics.

But the bold work of Copernicus did not go far enough. Early in the seventeenth century, Kepler a young German scholar, noticed that the Copernican model differed from observation by just a whisker, eight minutes of arc, for the orbit of Mars. Kepler had inherited the meticulous observations of his mentor Tycho Brahe [5], and a lesser mortal would have put down this minor discrepancy to an error in observation. On the contrary, Kepler was convinced that the observations were correct and that the discrepancy pointed to a reformation of Astronomy, as he put it.

Kepler in another counterintuitive leap of faith proposed his first two laws of planetary motion in 1609. Some years later the third law followed. Crucially the orbits were ellipses. This went blatantly against Plato's picture of perfection that had survived two thousand years. With a single ellipse Kepler could wipe out the minute discrepancy between theory and observation, for the planet Mars. There were different ellipses too for other

planets. The tangle of crystalline material spheres which had withstood two millennia of scrutiny, finally came crashing down. (Cf.Fig.1.2).

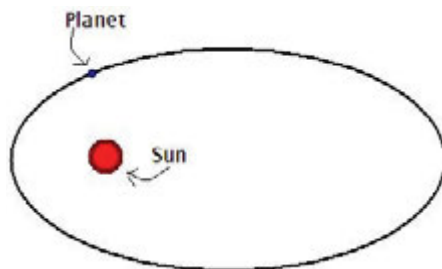


Fig. 1.2 An elliptic orbit

Kepler's third law related the sizes of the orbits of the planets to the time taken by the planets to go round the sun couched in a precise mathematical language. Indeed this was the beginning of modern science.

In hindsight, what the Greeks had tried to do was, approximate a simple ellipse by a series of complicated "perfect" circles. The larger implication of this minute correction was this: The ellipses destroyed the crystal spheres holding up the sun, moon, planets and the stars. And – the age old question once again returned to haunt. Why don't the moon, the planets and so forth crash down?

This question was answered by the brilliant British scientist, Sir Isaac Newton. He first crafted the laws of mechanics which were based on ideas developed a little earlier by the Italian scholar Galilei Galileo. Next he introduced his Theory of Gravitation. Kepler's purely observational laws could now be explained from theory.

Newton's answer to the age old puzzle was actually opposite to what we might naively expect. There was no counterbalancing force to halt the planets from plummeting down. Such a force, as we will see, came from

Einstein much later. Rather it was the attractive gravitational force which held aloft these objects in their orbits! How could that be?

First we should realize that for thousands of years people had taken it for granted that a force was needed only to move an object. Even Aristotle the famous Greek had said so. On the contrary Galileo and Newton noticed that without any force an object could be stationary or it could even move with uniform speed. A force was needed only to change the speed or direction of motion. This was the content of Newton's law of inertia.

So, let us consider the moon going round the earth for example. If suddenly the gravitational force was switched off, what would happen? Rather than plummet, the moon would rush off in a straight line at a tangent to its orbit. This is similar to what happens when a stone whirling at the end of a string is suddenly released (Cf.Fig.1.3). The attractive gravitational force would actually tug at the moon, pull it in and barely keeping it in its orbit.

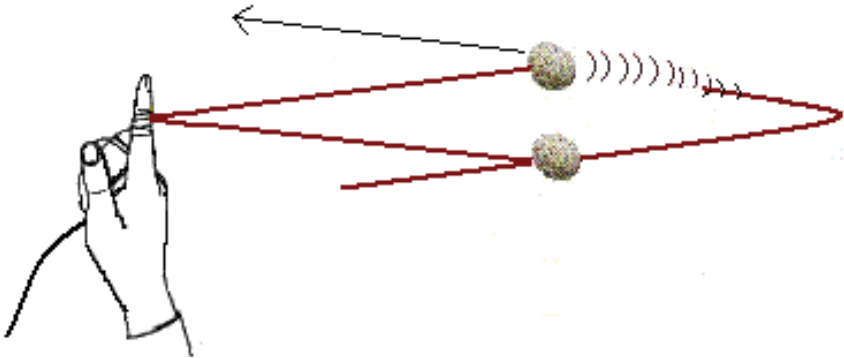


Fig. 1.3 The stone tends to rush off along the tangent if the string snaps

The beautiful edifice of Newtonian mechanics which demolished the Greek crystal palaces dominated the scientific scene for a few centuries - less than a tenth of the life of the Greek model itself. There was an absolute space, while time was separate. Space was a container a platform on which actors like matter, force and energy played their roles. Time too was

absolute. The present moment “now”, meant the same for a person on the street or an extragalactic being. A meter or a second were universal. All this is, of course “commonsense”. Albert Einstein would say, the Lord is subtle, but he is not malicious. The Lord though defies “commonsense” as we will discover.

.....

This page intentionally left blank

Chapter 2

You can be younger than your grandson

“I want to know how God created this world. I am not interested in this or that phenomenon, in the spectrum of this or that element. I want to know His thoughts, the rest are details.”

A. Einstein

The laws that emerged from the work of Galileo, Kepler and Newton constituted what we today call mechanics. The question whether these laws are valid for all observers or for some privileged observers— and if so to whom – troubled Newton. This question is not immediately obvious. For example if we say that the laws are true as seen from the earth, then the question would prop up, what about the laws as seen by some one on the planet Jupiter or elsewhere? The joke is that Newton’s laws are not true on the earth itself, as we will see!

In the Greek model the earth was at the centre and stationary and such a question did not really bother anyone. All that we had to say was that the laws were true for any person who was at absolute rest like the earth itself. This would not be the case if the earth were hurtling through space.

Newton’s answer to the question was that the laws would be true for an observer for whom the distant stars were fixed, that is stationary. By this yardstick the laws would not be true on the earth, as noted. This is because the distant stars rise and set – they are not stationary. Today we would say that Newton’s laws could be observed by one for whom the distant stars would appear stationary for example, a futuristic astronaut in a voyage towards some distant star. Such an observer, for whom the law of inertia and other laws hold is called an inertial observer.

The laws would not be true on the earth because a person on the earth is not inertial. This is brought out quite dramatically by the pendulum

experiment performed by the French scientist, Leon Foucault in Paris in the nineteenth century (Cf.Fig.2.1). He observed a long swinging pendulum. Such a pendulum should oscillate only in a single vertical plane under the influence of the earth's gravity. This plane however should not change, if we are indeed inertial observers. That is because there is no tangential force working on the pendulum bob, perpendicular to the vertical plane of its oscillation. Let us say that there is no horizontal force acting on the pendulum. However Foucault demonstrated that the plane does indeed change, in fact it rotates once in a little under thirty three hours [6]. This figure varies from place to place.

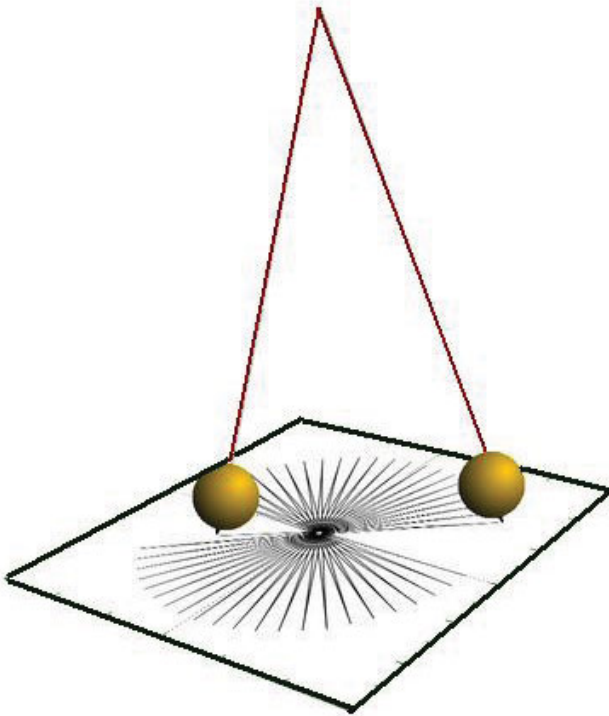


Fig. 2.1 Foucault's pendulum

We can easily guess that this is because, the earth below the Foucault pendulum behaves like a rotating platform. At the North Pole itself, when

.....

you are on the earth's axis of spin, the plane would rotate once in twenty four hours. That is for an observer not in contact with the earth, the pendulum would continue to swing in the same plane according to Newton's laws, but for an earth observer who is unaware of the fact that the earth below him is rotating, the plane of swing appears to rotate in the opposite direction. Apart from this however the earth approximates an inertial frame in which Newton's laws are valid.

Now let us suppose that we are in a spaceship – let's call it Space Lab – rushing through space at a uniform speed, as seen by someone on earth. If we perform experiments in our Lab, then just like Newton, we would soon enough rediscover all the laws of mechanics. It is irrelevant that we are moving (with a uniform speed). From this point of view we have as much right as any to call ourselves inertial observers. (As we will see soon, this would not be the case if our spaceship was accelerating). That all “inertial” observers have the same laws of mechanics is called the Principle of Galilean Relativity.

Apart from mechanics another curious phenomenon that was known for at least two thousand years was that of electricity—this was the strange behavior that was witnessed when some substances like amber were rubbed vigorously. This experience was formalized at the end of the eighteenth century: The electric charges exerted forces much like Newton's gravitational force. In fact the French experimenter, Coulomb discovered, using what is called a torsion balance that the electric forces mimic the gravitational force with the same inverse dependence of the square of the distance. The gravitational force depended directly on the masses of the two objects, while the electric force depended on their charges. From this point of view, we could even call the mass, the gravitational charge.

However there were two crucial differences. Firstly the gravitational force is always attractive, whereas the electric force came in two varieties – as an attraction between unlike charges, that is a positive charge and a negative charge, or as a repulsion between like charges. Secondly, while in principle the gravitational force could vary continuously in strength, with the mass of the objects, the electric force came with discrete charges. Thus there could be one, or two or three ... charges with nothing like one and a half charge. In contrast the mass, which plays the role of charge in gravitation, can be anything.

Shortly thereafter, early in the nineteenth century, Hans Christian Oersted performed an experiment which was sensational. By now it was known that an electric current was nothing more than a stream of moving charges,

much like a stream of water. The big surprise was that such an electric current could deflect a magnetic compass. Though magnetism had been known for many centuries, its link with electricity came as a big big surprise. Other experiments soon followed.

Ampere for instance showed that if electric currents were passing through two parallel wires, there was a new force between these wires which resembled magnetic effects. There was a twist in the plot here. The theory of electric charges so far was on the lines of Newtonian mechanics and gravitation. Now it appeared that the force between wires was perpendicular to the direction of motion, something which we do not encounter in Newtonian mechanics.

Around the middle of the nineteenth century it was realized that electricity and magnetism were not the two different phenomena they were supposed to have been. Rather they were intimately interlinked. This was called electromagnetism. Only when the electric charges were moving slowly or were at rest could we speak about electricity as separate from magnetism. The British physicist James Clerk Maxwell worked out the detailed mathematical behavior of this new force of electromagnetism. It appeared that a moving charge would emit radiation that would travel through space and impinge upon other charges, rather like the ripples that glide across the surface of a pond when a stone is thrown on it. Further the speed with which such so called electromagnetic waves or ripples traveled, turned out to be miraculously the same as the speed of light. Today our entire infrastructure of telecommunications rests on this electromagnetic theory. The question was now being asked, was light itself some form of electromagnetic radiation?

What you might well wonder is, is there a principle of relativity for the new electromagnetic laws as for Newton's laws of mechanics? In other words could we say that the astronaut in the uniformly moving Space Lab, but otherwise cut off from the outside world discover the same laws as Maxwell did on the earth? At first sight the answer would appear to be easy— No. This is because if there were two charges at rest within our Space Lab, then we who are in it would observe that they interact according to Coulomb's law for electric charges. But, from the earth perspective, the two charges are moving with the Space Lab and so constitute currents. These interact in a completely different way, via Ampere's laws. (Cf.Fig.(2.2)).

So our description would be very different from that on the earth. But, as we will see soon, there was a mind blowing twist.

Newton's concept of time had been pretty much the same as that coming

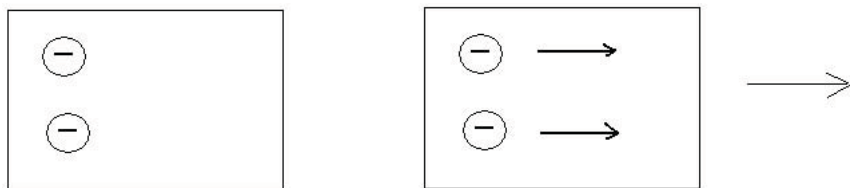


Fig. 2.2 Stationary and moving charges

down to us over the ages. In particular an instant of time had the same meaning for observers anywhere in the universe. So if a star exploded now, at the same time as a bird alighting on the branch of a tree, this statement was true universally. There was no way a person in another galaxy, for example would see this event as a star exploding first and several minutes later a bird alighting on the tree, or the other way round. In other words time was absolute. Not that there was any experiment that definitely showed the absoluteness of time. Nevertheless this had been taken for granted from time immemorial.

However towards the end of the nineteenth century some experiments threw up troublesome results. These were a series of experiments carried out by Albert Michelson and Edward Morley in the US. But the story really began in 1675 [7]. Till then, people had taken it for granted that light reached one point from another instantly, that is travelled with infinite speed. That year, a Danish astronomer, Olaf Romer, brilliantly conjectured that light travels with a finite speed. This conjecture was inspired by the invention of telescopes some sixty five years earlier. Around the mid seventeenth century a number of astronomers observed the eclipses of the satellites of the planet Jupiter. These eclipses were generally observed before and after Jupiter's opposition, when Jupiter and the Sun were on opposite sides of the earth as those were favourable times. However the eclipse times did not match those when Jupiter was near a conjunction, that is on the same side of the earth as the Sun. There was a difference of more than ten minutes. Romer speculated that this difference was due to the different distances of Jupiter on the one hand and the fact that light travelled with a finite velocity on the other.

To understand the Michelson-Morley experiment, imagine that we are on

Full document details: WSPC WHN UNI TK A U-TRN 2009

the seashore watching a ship sail by, let us say at a speed of forty kilometers per hour. If there were a boy on the deck running in the same direction with a speed of twenty kilometers per hour, to us the boy would appear to be moving with a speed of forty plus twenty, that is sixty kilometers per hour. In case the boy was running in a direction opposite to that of the ship, we would say that he was actually moving with a speed of forty minus twenty that is twenty kilometers per hour. (Cf.Fig.2.3).

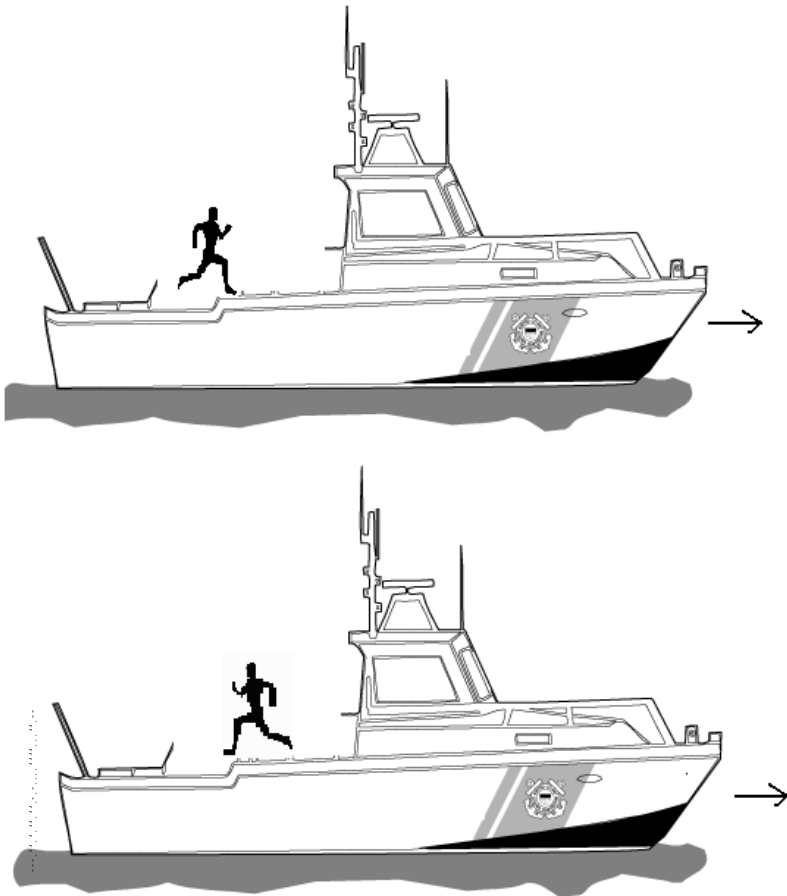


Fig. 2.3 Boy running with and against the ship's motion

This is commonsense and it is also the result given by Newtonian mechanics.

Now let us replace the moving ship with the earth. Remember in its own right the earth is a space ship, rushing around the sun with the enormous speed of about thirty kilometers per second which we will denote by v . Let the boy be replaced by a ray of light which moves with a speed c which is ten thousand times greater than v . By the above commonsense or Newtonian mechanics reasoning, we will conclude that, a ray of light traveling in the direction of the earth's motion towards a mirror would move with a speed $c - v$ as the mirror rushes away from the ray due to the earth's motion. After reflection from the mirror it would return with a speed $c + v$ because we on the earth are rushing to receive the ray. If on the other hand, light were traveling towards the mirror in a direction perpendicular to that of the earth's motion, its up and down journey would be carried out at the same speed c . The point is, to simplify matters, there would be a minute difference between the return times of light in these cases, even if the distance covered would be the same.

Michelson and Morley devised an experiment which was sensitive enough to detect this difference, even though it would be very minute [8]. However try as they would, such a difference did not show up. This was a huge embarrassment and puzzle for physicists. It upturns our logic. It is as if the boy on the ship would appear to be moving with the same speed – up or down. A couple of way out hypotheses were put forward to explain the absence of this miniscule difference, or in other words why there was no difference in the time of arrival of light in either case.

One of these was put forward by the great French mathematician and physicist Henri Poincaré. His ingenious idea was that we had taken it for granted that time intervals measured by clocks moving along and perpendicular to that of the earth's motion were the same: If a clock were traveling along the earth's direction of motion and another perpendicular to it, one second on either clock would have the same meaning. But suppose a second along the direction of the earth's motion was actually a wee bit longer than that in a perpendicular direction? Sounds preposterous doesn't it? In other words he assumed that time would dilate with motion. Poincaré could manipulate such a minute difference or dilation of time to deduce that there would be no difference in the arrival times of light, which would of course explain the results of the Michelson – Morley experiment.

A renowned physicist, H.A. Lorentz of Holland, as also the Irish physicist G.F. Fitzgerald came up with a different though equally brazen explana-

tion. They noticed that we had taken it for granted all along that the length interval, for example a foot rule in the direction of motion was the same as a foot rule perpendicular to the direction of motion. This of course was commonsense and time tested for thousands of years. But suppose, however improbable it may seem, a foot rule in the direction of motion were less than one in a perpendicular direction, though by a very minute amount? This would also explain the arrival time puzzle.

It was left to find out which of the two explanations would agree with other experiments. Interestingly in hindsight, if a hypothetical experiment were done to determine if Poincaré was right or Lorentz, such an experiment would have shown that both were correct, thus compounding the puzzle!

It was at this stage that Albert Einstein, then a lowly patent clerk in Switzerland wrote an article with a rather uninspiring title, "On the Electrodynamics of Moving Bodies". Einstein was a run of the mill student, who in fact was forced to leave his school in Munich [9]. Thanks to his friend, the mathematician Marcell Grossman, he could study at the Swiss Federal Institute and moreover got his patent clerk job. In this paper Einstein assumed, that is took as postulates two mutually contradictory statements. The first was that the laws of physics, including electrodynamics would be the same for all observers moving with a constant velocity with respect to each other.

He wrote, "Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relative to the "light medium," suggest that the phenomena of electrodynamics, as well as of mechanics, possess no properties corresponding to the idea of absolute rest. They suggest rather that ... the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good. We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body." Now the first postulate as we saw, was correct for Newtonian mechanics, but we argued that it would be false for electromagnetism. It would lead precisely to the conclusion that the Michelson-Morley experiment should show the difference between the arrival times of light referred to.

The second postulate in a sense contradicted the first "impossible" hypothesis. This was that light would travel with the same speed for all such observers, that is the $c + v$ and $c - v$ speeds would be the same. This of

course would contradict the commonsense results or in more technical language the relativity of Newtonian mechanics according to which light would have different speeds going up and coming down. This was an equally impossible hypothesis.

But Einstein argued that if we put these two contradictory postulates together, then the results of all experiments could be explained! In that 1905 paper, as we saw Einstein declared, "... the same laws of electrodynamics and optics will be valid for all frames of reference for which the laws of mechanics hold good". That is of utmost importance. In any case, as the Late Nobel Laureate Professor Abdus Salam would say, "Experiment is at the heart of physics". You can put forward bizarre hypotheses, but at the end of the day, the results must be in tune with observation. If all the crows we see are white, then so be it!

But how could this be? Einstein explained that the exotic hypotheses of both Poincaré and Lorentz were correct. The contradiction appears when we carry over the baggage of Newton's ideas of space and time, according to which space intervals and time intervals, as we saw earlier, had an absolute meaning, independent of who was measuring them. Einstein argued, experiment showed that this was not the case, and experiment is the key that lays down the rules, not some preconceived "commonsense" notions that we may have, which are really experience based prejudices masquerading as commonsense. In other words our concepts of space and time were based on preconceived notions, unrelated to the new experimental reality. Einstein brought in a physical concept of space and time, based on experiments. Of course we do not need to be too critical of ourselves because the differences which Einstein brought in are minute indeed, and observable only at very high speeds. For most practical purposes we can carry on with Newtonian ideas.

There are two morals which we can draw from the above story. The first is that the laws of physics may be correct, but within the limitations of our prevailing experimental ability. When newer and more precise observations are available, then the earlier laws could be challenged - they could have reached the limits of their validity.

The second lesson – though this is not so obvious – is that ultimately science is a unifier. Thus the Poincaré time dilatation or the Lorentz length contraction were both correct, though ad hoc. It was Einstein's work which at a single stroke brought out both these seemingly different results, it unified different concepts. In particular, we had thought of space and time as two separate unrelated concepts. Einstein's work showed that, rather we

had to think of a single idea, spacetime. Our old concepts are however still approximately correct in the normal situations we encounter, for example the orbits of the planets around the sun and so on.

Einstein's two apparently contradictory postulates, together called the Special Theory of Relativity, no doubt explained the Michelson-Morley experiment. But is there a more direct way of experimentally observing, for example time dilatation? This time dilatation would mean that if your grandfather were in the Space Lab traveling very fast, with nearly the speed of light, then every hour by his clock would be several hours by your clock, so that ultimately, for example it is possible to think of a situation where a couple of years for him would be something like a hundred years for you. You could then end up being much older than your living grandfather when you greet him at the end of his trip.

Is there any way we can test this stunning, seemingly absurd prediction? Surprisingly the answer is yes. Traveling in a rocket with such high speeds is beyond our technological capability, but we could achieve the same conclusion in a more ingenious way. Neutrons it is well known decay into a proton and electron and a not fully understood practically massless particle called the neutrino, within a few minutes. We say that the half life of a neutron is about twelve minutes. This means if we have a hundred neutrons in a jar at this moment, after twelve minutes, there will be only fifty neutrons left, that is half of them would have decayed. However if the neutrons are moving very fast in a beam, what is called a neutron beam, it is found that their half life is prolonged, as if they live much longer. After twelve minutes, rather more than half the neutrons would be intact, that is would not have decayed. This is a dramatic confirmation of time dilatation. We can understand this strange, even commonsense defying idea that time dilates, by considering a simple clock. This consists of a source of light that can be switched on only for an instant and a mirror on top of the source. The light travels vertically upwards strikes the mirror and returns to be recorded by a counter. This interval is let us say one second. In one second light would have traveled a total of 300,000 kilometers, which means it traveled a 150,000 kilometers up and a 150,000 kilometers down in this time. That is like a round trip to the moon! But just suppose. Now let us suppose that we climb into our Space Lab with this clock as shown in the figure (Cf.Fig.2.4). For us, light would just go up and come down, but as seen by the stationary outside observer, light would have traveled along a triangular path. Each side is greater than 150,000 kilometers. So the interval between departure and return would be more

than one second, if light were traveling at the same speed for both, as Einstein suggested.

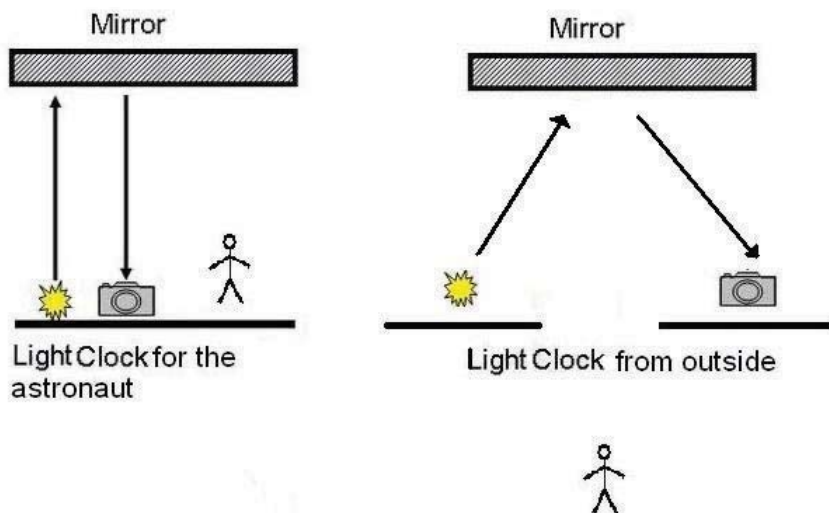


Fig. 2.4 Light Clock

This means that, firstly we or the astronaut would still calculate that one second has passed by this clock, whereas for the outside stationary observer, much more than a second has elapsed. So also for the neutrons in the beam, there is no change in their half life of twelve minutes whereas for the outside observer in the laboratory, the half life is much more than twelve minutes. We must remember that this is not just a physical effect. Everything – including the chemical, the biological, the physiological and even the psychological – is affected by the difference because time underwrites everything. In other words, your grandfather, stepping off the space ship at the end of the trip, would genuinely feel younger, and you would genuinely feel older!

In Newtonian mechanics there would have been no difference because the speed of light as seen by the outside observer would be a combination of the speed of our Space Lab and the speed of the clock. In other words it would be much more than the speed of light as noted by the observer with the clock. This extra speed would compensate for the extra distance traveled

by light as seen by the stationary observer and the nett result would be that both observers would measure the same one second. So the crucial point here is that the speed of light is the same for all observers moving relatively at a constant speed.

If we work out the math, then it turns out that there is another dramatic consequence. You might even call it mindboggling. Suppose your friend sitting in the same room lights a cigarette, and at exactly that instant there is an accident on the road outside. According to Newtonian ideas this would be the case for all observers including, for example someone living in Andromeda galaxy. This is what we call the absoluteness of simultaneity – it expresses the fact that an instant of time has the same universal meaning. Not so in relativity! Two such events may appear very differently to different observers. For one, the lighting of the cigarette could take place much before the accident while to another it could be the other way round. Does this mean that a son can be born before the birth of his father? No. The order of events cannot change if one of these events is the cause while the other event is the effect. The order of events can change, only if they are not related by the cause and effect relationship.

Now you may ask what happens if the relative speed of two observers is not constant? Suppose one observer is moving with an increasing speed, that is accelerating, as seen by the other observer. Then the above simple logic would not hold. In fact Newton told us that acceleration is a manifestation of a force. So a new entity, force comes in with acceleration. This is the case with Newton's apple or any other object falling down to the earth. If we release that object from a great height, at that instant of release, the object is not moving, that is it has zero speed. As time passes however its speed keeps increasing, and by the time it hits the ground it would be moving much faster. For instance if the release was from the hundredth storey of a Manhattan building, its speed as measured from the fiftieth floor would be faster, but its speed when it reaches the ground would be even faster. This is of course due to the gravitational force, as we all know. The pile driver used in constructions, works on this principle.

Starting with this idea Einstein conceived of the following bizarre experiment, a thought experiment. A thought experiment is one which may not actually be performable, because of the technology or circumstances such an experiment requires. Nevertheless such an experiment does not violate any of the laws of physics, and would give a valid result if actually performed. To understand this experiment, let us again climb into our Space Lab, which we will use as an elevator – into outer space. Suppose you

drop a ball from a height. This ball would immediately fall and hit the floor of the elevator. But now suppose that the Space Lab elevator were itself falling down with the same acceleration. This could happen in real life if the elevator cable snaps as it is coming down from the hundredth floor. Now what would happen is that the ball would be racing towards the elevator floor tugged by gravity, but the elevator floor itself will be racing away from it with the same speed and acceleration. So the ball just would not reach the elevator floor (Cf.Fig.2.5), (Cf.Fig.2.6). It is almost as if Newton's apple, having got detached from the branch of the tree remained there without hitting the ground! In other words it would be as if gravity had been switched off! Yes, the mighty force of gravity switched off!

Now we go further. Suppose you were in the Space Lab that is floating in deep outer space, far away from any stars, planets and so forth. You would then be floating weightlessly in the Space Lab. Now suppose by some means, for example using an attached high power rocket, the elevator were given an acceleration upwards of exactly the same magnitude as that encountered on the earth (but downwards). Then while you would have been floating alright, the elevator floor would come and crash into you just as on the earth you would fall and hit the elevator floor. In fact there is no difference between the two scenarios. You hitting the Space Lab floor, or the floor hitting you. Einstein argued that the force of gravitation could be removed or created by a suitable acceleration. This is a far cry from Newton's gravitation which was an actual force, much like the force with which we pull or push a wheel barrow for example.

In fact Einstein's proposal that gravitation and acceleration, to put it simply are equivalent solves another problem that was vexing him for a long time. This had to do with one of the experiments which made Galileo famous more than three centuries earlier. We all know how he was supposed to have puffed up the stairs of the leaning tower of Pisa and from the top dropped two spheres one made of wood and the other of metal. (According to some, Galileo did not actually do this!) [10]. Both the spheres are supposed to have hit the ground at the same time even though they had different weights. This demonstrated that the velocity and acceleration caused by the earth's gravity did not depend on the actual mass of the object concerned. On the other hand we also know that according to Newton's law of gravitation, this force depends very much on the mass. So some how the mass gets cancelled by his laws of mechanics: Because, the force is the mass times the acceleration.

We must pause for a moment to appreciate a nuance. There are two dif-

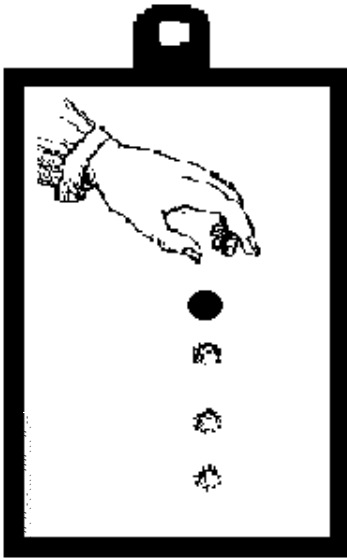


Fig. 2.5 Ball falling in a stationary elevator

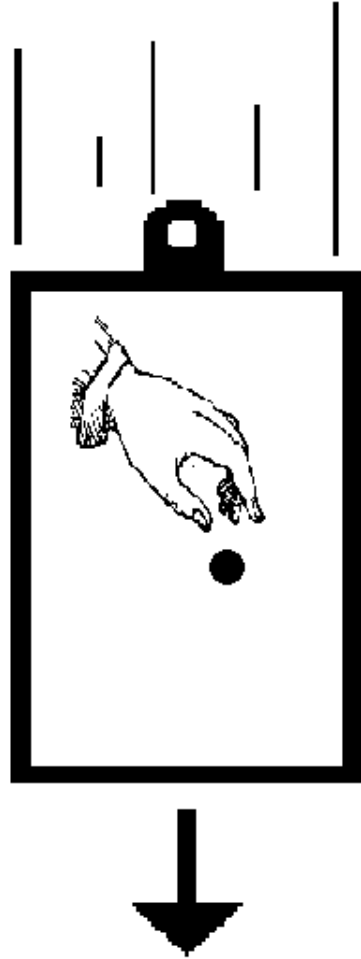


Fig. 2.6 Ball floating in an accelerated elevator

ferent facets here. One is Newton's laws of mechanics which are true for gravitation as well as other forces. They are not gravitation specific. The other is, Newton's Law of Gravitation which has nothing to do with his laws of mechanics. In this law, he introduced a force, called the gravitational force and characterized it, quite independently of his mechanics. This force is directly proportional to the body's mass or "gravitational charge" much like the electric force is proportional to the electric charge. It so happens,

almost miraculously, that the acceleration of mechanics is proportional to this same “gravitational charge”. Not the electrical charge.

To get further insight, suppose we let go two spheres in our Space Lab, from a height. Further suppose that both these spheres are of very different sizes, material and masses. If the elevator were far far away, deep in inter stellar space, then like ourselves, these two spheres would float. Now the elevator begins to accelerate with exactly the same value as the acceleration due to gravity on the earth. In no time the floor of the elevator would rush and strike the two spheres at the same instant. (Or the two spheres would rush down and hit the floor at the same instant, looking at it another way). This collision would moreover take place at the same instant independent of the make up of the spheres. This is because the collision has nothing to do with the objects themselves, but rather is due to the movement of the Space Lab. Now Einstein was claiming that this motion which mimicked gravitation, was the same as gravitation. There was no separate force called gravitation. If this be so then, the acceleration of gravitation does not depend on the make up or mass of the material on which it is acting. Next Einstein had to answer another question. He already had said that the laws of mechanics and electromagnetism were the same for all inertial observers including our astronaut rushing in the Space Lab with uniform speed. What about the accelerating Space Lab, which is no longer moving with uniform speed? Einstein claimed that the astronaut would also deduce the same laws of mechanics and electromagnetism as the inertial observer, including an astronaut in an uniformly moving spaceship. We saw that the equivalence of the laws of mechanics and electromagnetism for uniformly traveling astronauts could only be possible if we profoundly changed our ideas of space and time.

It turns out that claiming these laws to be the same for accelerating astronauts too, would lead to some equally profound implications. A simple way of seeing what this means in electromagnetism is to consider the motion of a ray of light, which we know always moves along a straight line—even with special relativity. Let us now consider a ray of light that is flashed diagonally across our Space Lab.

Suppose first, the spaceship is at rest, that is floating freely in deep outer space. A ray of light is flashed from one side of the elevator to the other, parallel to the floor—or so says our astronaut. At that very instant the elevator starts moving downwards with an uniform speed. Our description from outside would be slightly different. By the time the ray of light traveled one centimeter, parallel to the floor, the floor itself has come down by let us say

one millimeter. By the time the ray would travel another centimeter, the uniformly moving elevator would come down another millimeter, carrying the floor with it and so on. The nett result is that the ray of light would to us who are outside appear to move at an angle to the floor, but nevertheless in a straight line (Cf.Fig.2.7).

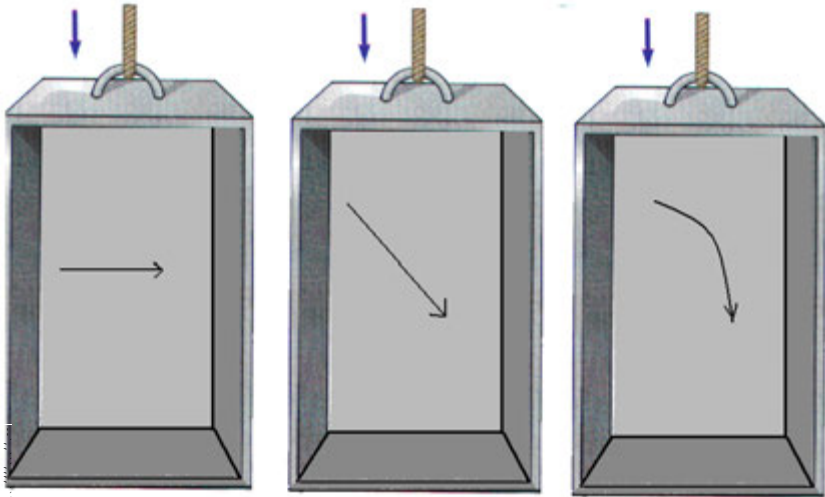


Fig. 2.7 The deviation and bending of light

Suddenly the spaceship is accelerated. Let us say that as before, by the time the ray of light travels one centimeter parallel to the floor our Space Lab comes down by one millimeter. But by the time the ray of light would have traversed the next centimeter, the floor would have come down by more than one millimeter because its speed is now no longer constant but rather is increasing. Let us say it has moved by two millimeters. By the time the ray of light travels yet another centimeter, this time the floor would have plunged down by rather more than two millimeters, let us say by three millimeters. If we now trace the path of a light ray as seen by us from outside, it would not only appear slanting, but it would actually be a curve. That is light, contrary to everything that we have been taught ap-

pears to be bending. Light would no longer appear to travel along straight lines! (Cf.Fig.2.7) This is the new effect which we will observe if we accept Einstein's claim that all laws of physics, including electromagnetism would be the same for all observers, irrespective of whether they are moving uniformly or accelerating.

One can put forward any consistent hypothesis or model, but ultimately whether this model is meaningful or not depends on the predictions it makes and whether these predictions can be tested. Clearly no one would accept Einstein's bizarre ideas without solid observational proof. This came about just a few years after he predicted what may be called his gravitational bending of light. It is called gravitational bending, because as we saw acceleration and gravitation are one and the same.

In 1919 there was a total solar eclipse which was visible from parts of Africa. Such an eclipse could provide an opportunity to test Einstein's ideas. This is because when the sun gets eclipsed, that is its face is just covered by the moon which comes exactly in-between at that time, then we begin to see the stars which are pretty close to the Sun. Close here means, close as they appear. Of course the stars are there even if there were no eclipse, but then we cannot see them. So suppose we observe a nearby star just as it becomes visible when the eclipse starts. This means light from the star is reaching us. This light has to graze past the sun, because the star is actually much much farther away. If this ray of star light should be bent by the sun's gravitation, that would mean that the star as we see it would appear a little higher than it actually is.

Sir Arthur Eddington the celebrated British Physicist headed an expedition to the West coast of Africa to check this out and photographed stars very close to the Sun. He then compared their positions on the photograph to their actual catalogued positions and found that indeed they appeared in the photographic plates, that is to our eyes as being a little shifted upwards. This was a dramatic confirmation of the strange theory of gravitational bending of light, (Cf.Fig.2.8).

There are other forces which can be "created" by motion and which are coupled to the gravitational "charge" or mass, exactly like the force created by the accelerating spaceship. For example let our Space Lab, which till then was either uniformly moving or stationary, suddenly get into a spin. The astronaut would be pushed to the side of the spaceship due to the centrifugal force. This is the same force that you feel on your hand, when you hold the open door of your car as it swerves - the centrifugal force would throw the door open if you were not pulling it in. This centrifugal

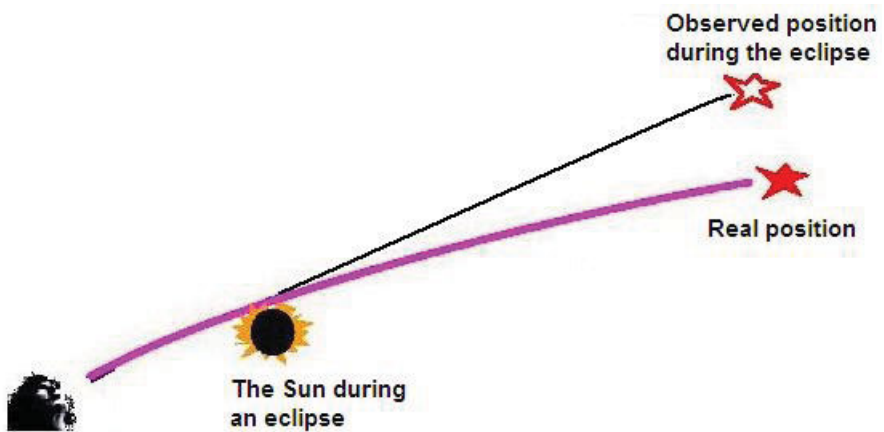


Fig. 2.8 The bending of light observed during a total solar eclipse

force depends on mass in the same way as gravitation or the force of acceleration - if the astronaut were twice as massive, he would feel twice the force. There is no reason why we cannot carry over the above reasoning of the accelerating spaceship to this spinning spaceship. Once again we can conclude that a ray of light would bend towards the direction in which the force is pointing.

What does this bending mean? Suppose light were like a boy running through a narrow corridor. If the corridor were circular, then the boy concentrating on the ground below would think that he is running straight. He would be very surprised to find himself back where he started after running the length of the corridor in what he would suppose is a straight line. Einstein said, so also the ray of light would be traveling in a “straight line” through space, except that this space or more correctly spacetime is bent like the corridor. The bending of spacetime was yet another effect that Einstein introduced - this time it was the effect of gravitation or the equivalent force due to acceleration.

We already saw that time gets dilated because of speed - the greater the speed, the greater the dilation. Remember the fast moving neutrons and their life time which increases with speed? Now let's see what happens if our Space Lab were crashing on to the earth. As it approaches closer to the earth, under gravity, its speed would increase. So at a certain height time would have dilated by a certain amount. That is, one second for the

astronaut would appear to be two seconds on the earth for us let us say. Soon the astronaut would be closer to us and would be crashing even faster. So his one second would be even more to us, shall we say it is four seconds. This means at a certain height the one second is two seconds and at a lower height it is four seconds, all this being due to gravity. There would thus be a difference in time intervals at different heights.

There is another way of looking at this. Let us consider, for example the sun and the earth. As light leaves the sun, it begins to loose energy, because the gravitational field of the sun drops with distance. Loosing energy means that the frequency of this light begins to fall, because as we will see, the frequency or rapidity of oscillation is directly related to the energy. So if we are on the earth, it would appear, using our light clock again, that time intervals near the sun are longer. Equivalently time slows down near the sun or speeds up near the earth which is much less massive compared to the sun, and so has less gravitational energy.

To quote the inimitable American physicist, George Gamow [11], "A typist working on the first floor of the Empire State buildings will age more slowly than her twin sister working on the top floor. The difference will be very small however; it can be calculated that in ten years the girl on the first floor will be a few millionths of a second younger than her twin on the top floor."

We must remember that when we say time slows down, that means everything that goes with time also slows down - the rates at which electrons orbit atoms, the rate of chemical and biochemical reactions and so on as already noted (Cf.Fig.(2.9)). So with a suitable arrangement, we could ensure, in principle, that one of the twins is an old hag while the other is still a babe in arms! Space and time are much more mysterious than we can ever imagine!

You might well ask, "We could verify that time dilates in special relativity, for example by observing neutrons in a beam. Can we similarly check out this gravitational time increase?" Not so likely with the Empire State Building, as you might guess. Nevertheless experiments have been performed, starting 1962. Two very accurate clocks were used, one at the top and the other at the bottom of a water tower. The clock below, being nearer to the earth was in a stronger gravitational field, and indeed it was found to run slower, in agreement with general relativity.

Moreover we must remember we are constantly receiving powerful radiation from massive objects in deep outer space, objects like quasars. Because of the power gravitational fields at these objects, compared to the low grav-

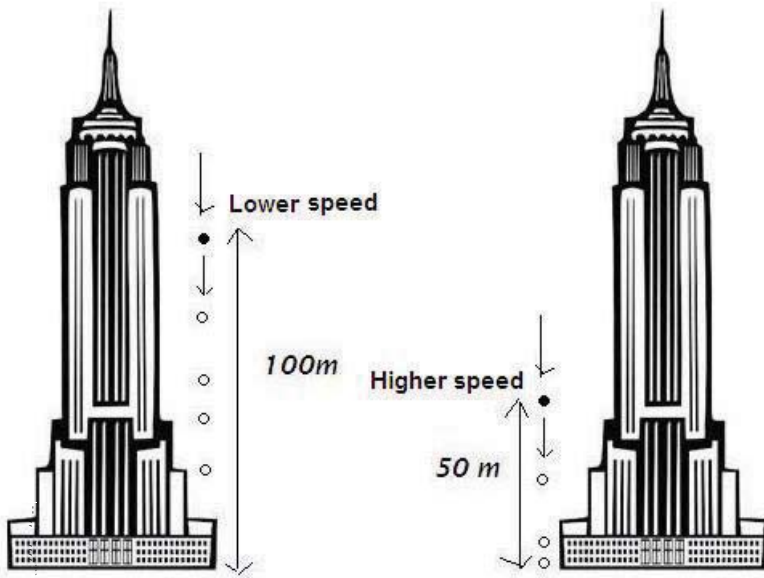


Fig. 2.9 Different speeds of a falling object at different heights

itation on the earth, by the time the radiation reaches us, it would have traveled through different “time zones”. Time zones in the sense that intervals there would be different: seconds there compared to seconds here. This would effect the frequency or wavelength of the radiation. It is called the gravitational red shift, because light from there wouldbe redder than its counterpart light here. It is believed that such gravitational red shifts have been observed, though by no means is this verdict unanimous.

Chapter 3

God does not play dice, or does He?

“It may happen, it may not happen”

– Ancient Indian saying.

3.1 The Classical Catastrophe

Classical physics developed over the 17th, 18th and 19th centuries to reach a degree of precision and perfection that was as impressive as the Ptolemaic model, two thousand years earlier. Indeed, delivering the inaugural lecture at Cambridge University in 1871, the doyen of electromagnetic theory, James Clerk Maxwell observed “In a few years, all the great physical constants will have been approximately estimated, and ... the only occupation which will then be left to the men of science will be to carry these measurements to another place of decimals.” [12] Classical physics later came to include also Einstein’s special and general theories of relativity. So how does man’s concept and knowledge of the universe develop? We could well imagine that it develops progressively, one step leading to another. But then the Greek Ptolemaic model held sway for some fifteen hundred years and then collapsed in toto. Thomas Kuhn, the philosopher of science suggests that this is how science progresses [13]. It develops impressively up to a point and then collapses unable to confront new observations, so that a new edifice based on new thinking is built up over the ruins of the past. This is much like the monuments left behind by history. However difficult it was for a scientist to have imagined in the earlier part of the twentieth century, classical physics too suffered a similar tumble. It was a beautiful theory that explained just about everything—but in the large scale, the macro or gross world.

New experimental inputs came in from an unexpected frontier – a study of atomic systems in the early years of the twentieth century. These threw up results which just could not be explained by classical physics. They formed a huge enigma - it was only by discarding the old concepts and invoking radically new hypotheses that the new evidence could be explained. These new experimental findings came from different directions - from optics, from thermodynamics, from atomic physics and also from completely new fields [14].

In optics for example, it was well known that light was emitted by substances when they were heated. For instance if an iron rod is inserted into a burning flame, after a certain time, it begins to glow. We could analyze the light which the rod emits by looking at it through an instrument called the spectroscope which, to put it simply, breaks up light into its constituent colours by using a prism. We then begin to see colored lines. Classical physics could explain why the rod should emit light - it would say that the heat of the flame causes the electrons in the rod to accelerate, and when electrons accelerate they emit light or more generally electromagnetic radiation.

However what puzzled scientists was that the experiments brought out a series of such spectral or colored lines and not a rainbow type of a continuous spectrum. For instance, when a Hydrogen atom is heated, it emits a characteristic set of such glowing lines - this set is called the Balmer series of lines. This series of lines was anything but random. Physicists could experimentally find a set of what are called spectroscopic terms that could be associated with the atoms of a substance. These mysterious numbers had an interesting characteristic - their differences gave the wavelengths or what is the same thing, the frequencies (which are reciprocal of the wavelengths) of the color of the spectral lines. This was called the Ritz combination principle, after its discoverer. The puzzle was, firstly the discrete lines and wavelengths rather than a continuous spread and secondly why this mysterious prescription called the Ritz combination principle put forward in 1908? There was no way that classical physics could explain this.

Another crisis for classical physics came from thermodynamics. It was well known that atomic systems could absorb or emit energy, when in contact with a suitable environment. As in the case of the light spectra, it was thought that this took place continuously. To put it a little more technically, the spectrum of radiation emitted by a hot object is continuous much like the continuity in colors we see in a rainbow. Or, so it was thought. We also knew that this spectrum covers a wide range of wavelengths or fre-

quencies. Moreover there was a wavelength at which there is a maximum intensity of radiation, and this depended on the temperature of the object that was radiating. This was the famous Rayleigh Jeans law, named after two famous British physicists, Lord Rayleigh and Sir James Jeans. According to this “law” the energy per unit volume is proportional to the square of the frequency (or inversely proportional to the square of the wavelength). This law agreed well with experiments - but as was realized, only at low frequencies or large wavelengths. The problem is that if we follow this law, then as the frequency increases the energy too increases without limit, which of course is impossible. This was called the ultra violet catastrophe because ultra violet rays have higher frequency compared to heat or light. It was an impasse for classical physics.

Then there was another interesting experiment which brought out what is called the photoelectric effect. This is crucial to us today because many modern optical devices are a direct consequence. These experiments show that when electromagnetic radiation strikes certain metals, then a stream of electrons is ejected. This stream constitutes what is called photoelectricity. To put it roughly, the puzzle here was that the energy of the emitted electrons depended on the frequency or wavelength of the incident radiation and not its intensity - the greater the frequency, the faster the electrons moved. By the way, an undulating wave has two lengths associated with it. Its height and width. The height measures the intensity, like the volume of sound. The width on the other hand describes the wavelength or frequency, like the pitch of sound. All this was again inexplicable from a classical point of view.

Historically the escape route from the ultra violet catastrophe of black body radiation, came first. This was due to the pioneering and ground breaking work of the German physicist Max Planck who in December 1900 conjectured that energy was not continuous but rather came in discrete packets or quanta. Furthermore the energy content of these quanta depended directly on their frequency. Once these non continuous and discrete quanta are introduced into the Rayleigh Jeans formula and subsequent calculations, the total energy turns out to be finite, as it should be. Revolutionary and even absurd as the idea might have been at that time, it had to be admitted that there was no other way out of the ultra violet catastrophe of infinite energy. In fact Planck himself distanced himself from this radical idea for many years [15].

Later, in 1905 Einstein used the new and radical theory of Max Planck to explain the photoelectric effect. He argued that the radiation impacting the

metal plates behaved not like waves, but rather like the discrete packets or quanta of Max Planck. This particle behavior of supposedly continuous radiation could then explain how the electrons could be ejected by the metals as a result of the impact. In one sense, as we saw, Planck's idea was not as new as it might seem. We know that, while Christian Huygens in the seventeenth century believed that light was a form of a wave, Newton had suggested that it was made up of corpuscles.

Around the same time Geiger of the Geiger counter fame and Marsden were performing experiments of another kind. Streams of what are called alpha particles which are nothing but the nuclei of Helium atoms, bombarded a thin gold foil. They passed through the foil and were detected on the other side. Classical ideas told us very unambiguously what was to be expected: A random set of points indicating the places where the alpha particles struck the detector. The actual result however was anything but this. Some of the particles had come out without much deviation as if they sailed through empty space. But a few – one in about twenty thousand had deviated quite a bit. There wasn't the random expected collection (Cf.Fig.3.1). How could we explain this discrepancy?

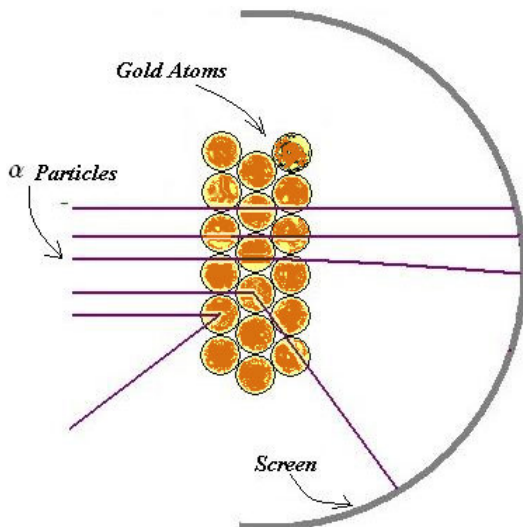


Fig. 3.1 Rutherford's Gold Foil Experiment

Till then it had been supposed that all matter was made up of electrons and perhaps protons in a sort of a random mixture. But the experiments could only mean that matter, that is atoms were very different. Sure, there were electrons. But these were far away from heavier central nuclei, with nothing but empty space in between. It's a bit like the solar system with the sun at the centre and then the planets spaced out at different distances, without anything in the intervening space. So those particles which went through the empty spaces came out without much of an effort, while those which encountered the central nucleus were knocked about quite a bit. There was hardly any third category.

So, could this mean that the atom was made up of a heavy central part, the nucleus with electrons relatively far away? This was proposed by an experimental physicist of New Zealand origin, working at the Cavendish Laboratory in England, Ernest Rutherford in 1911. But this leads to trouble. Because it was well known in classical theory that a collection of charges could not remain in equilibrium, if these charges were stationary. What would happen in this case is that the slightest of disturbances would send all the particles crashing into each other, and such an atom would be destroyed in less than a trice! In a sense, the universe of today would not exist!

This could only then mean, that the lighter electrons were not stationary, but rather like our planets, they would be orbiting the central nuclei. The atom began to look more and more like our solar system. Except that classical theory did not allow even this. That is because when an electron rushes through an orbit, it radiates electromagnetic waves, thereby losing energy. Such an orbiting electron would as a result spiral in towards the central nucleus. It is much like some of the space crafts which have spiraled in to crash into the earth, as they lost their speed due to frictional contact with the upper atmosphere. This way too, the atom would be destroyed in no time. Either way the universe would cease to exist in less than a wink. Some impasse! There appeared to be no way out.

A Danish Physicist, Neils Bohr joined Rutherford at Manchester. He put forward in 1913 a few bold ideas to resolve the impasse much as Einstein had done a little earlier. Bohr proposed a set of "illogical" postulates, that is 'don't ask me why' type of ideas. Their merit lay solely in the fact that they showed a way out of the impasse. Thus he proposed that electrons could continue to orbit the heavy central nuclei, but without losing any energy. This of course blatantly contradicted the laws of classical physics. Bohr claimed that electrons could use different discrete orbits, each with its

own energy - but here the analogy with solar system planets breaks down. A planet in the solar system is free to orbit the Sun with which ever energy is given to it. Bohr on the other hand restricted the energies only to certain allowed energy levels, that is a series of allowed values, and no value inbetween any two neighboring values. It is a bit like saying that the electron would orbit the nucleus with the energy one or the energy two or three and so on in some units, ignoring the infinite number of values between one and two, or two and three and so on.

Bohr went on to say that an electron with a certain energy could jump to an orbit with a different energy that was greater or even smaller. If the electron jumped to a smaller or lower energy orbit, then the difference of energy would precisely be some multiple of Planck's quantum, for example it could be two quanta or three quanta and so on. Conversely if the electron in jumping to another orbit gained energy, then it would have absorbed for example two or three or what ever number of quanta of energy from outside.

Bohr related the number of quanta of energy that an electron would emit with the spectroscopic numbers which gave if you remember, the spectral lines of the Ritz Combination Principle - one of the first of the paradoxical findings. Thus at one stroke Bohr could explain several experiments, although with the help of rather arbitrary and against the prevailing physics commonsense assumptions. However, Bohr hesitated to publish these radical ideas. Would anyone take him seriously? After he returned to Copenhagen, he was persuaded by Rutherford to go ahead and do so.

Albert Einstein too invoked Planck's quanta to explain the photoelectric effect. Thus, he argued, if the electromagnetic radiation impacting the metal plate were a series of quanta, rather than a stream of waves, then these quanta could kick out electrons which lay trapped in the middle requiring this exact same amount of energy to be liberated. That is how, the energy of these quanta or equivalently the frequency or wavelength of the radiation is crucial: waves with the wrong quanta, though plentiful in number would not do the trick. They would be like square pegs in a round hole.

These bold ideas constituted what we today call the Old Quantum Theory. It was both radical and ad hoc. It matched the junking of the Greek heavenly crystal spheres, acceptable only because this was the only way to explain experiments whereas the older ideas could not. What all this meant was that, in a sense, we had returned to Newton's earlier concept of light as being a stream of corpuscles, rather than a stream of waves as supposed by Huygens. It is rather curious that Albert Einstein got his Nobel Prize for

explaining the photoelectric effect, rather than for his deep studies of space and time. This was because, most scholars could not clearly understand Einstein's spacetime ideas [16].

3.2 Particles Disguised as Waves

So it was enough to consider electromagnetic radiation to be made up of discontinuous quanta or packets of energy just as we had convinced ourselves that these were continuous waves. But what followed challenged our thinking even more. These iconoclastic results were summarized by De Broglie a French nobleman of Italian origin, in his PhD thesis. He suggested in 1924 that matter too behaved in a contra manner: like waves, rather like the discrete standing waves on a string plugged at both ends, a guitar string, for example (Cf.Fig.3.2). And why not, if waves could behave like particles? The PhD committee was much too puzzled to pass a judgement. The members consulted Einstein who approved of this idea. Only then did De Broglie get his degree!

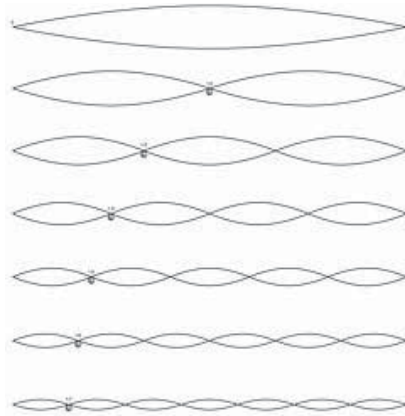


Fig. 3.2 Standing Wave

However, soon experimental confirmation for this strange idea came by. These were experiments performed in 1927 by two American physicists, C.J. Davisson and L.H. Germer. They bombarded an intermediate screen with a